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Title: Investigation of Radius of Curvature Measurements using Laser Interferometry

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Investigation of Radius of Curvature Measurements using Laser Interferometry

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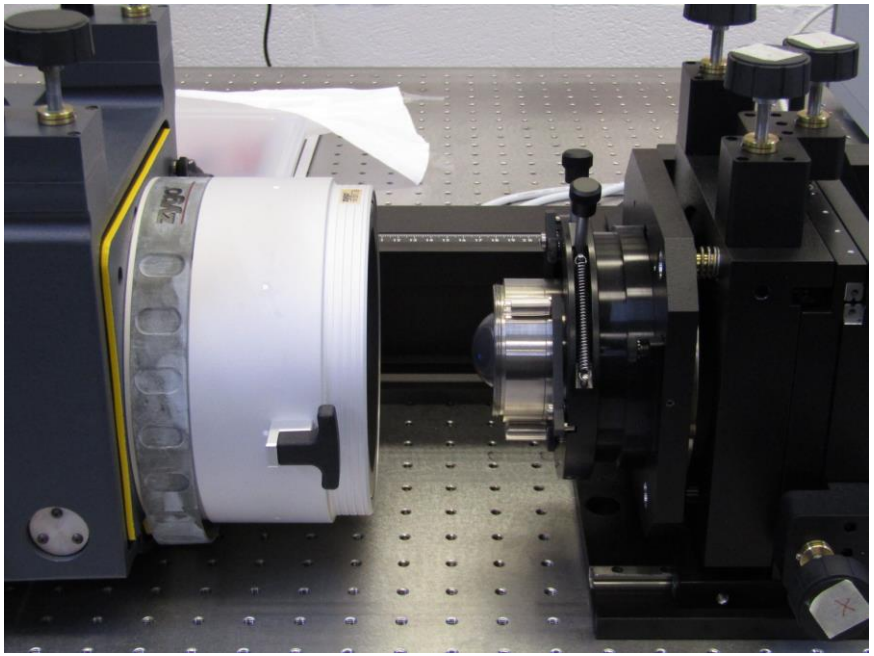
LA-UR-

Overview

- Introduction/Goals
- Literature Review
- Approach
- Data Collection
- Data Analysis
- Conclusion
- Future Work

Introduction/Goals

- Develop an application using a ZYGO Verifire for calibration of artifacts where the measurand is defined as a Radius of Curvature (ROC)
- Validate the measurements through an uncertainty analysis
- Determine if the calibration method is a viable alternative/option for calibration outside of current standard methodologies



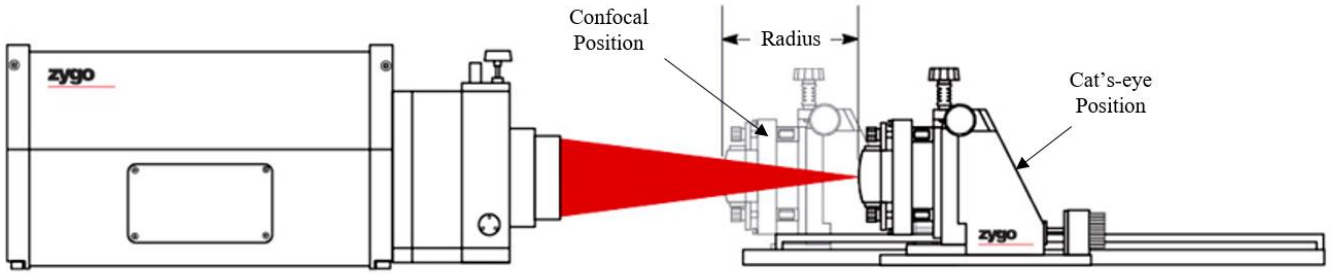
Applications

- Calibration:
  - Artifacts that have a measurand defined as an ROC
  - Optics that have a measurand defined as an ROC
  - Freeform optics
  - Artifacts that have a measurand defined as radius/diameter
    - CMM calibration/qualifications spheres used for probe calibration
- Form error measurements and residual error mapping
  - Roundness
  - Cylindricity
  - Height deviations from nominal surface

Source: *Taylor-Hobson*

Literature Review

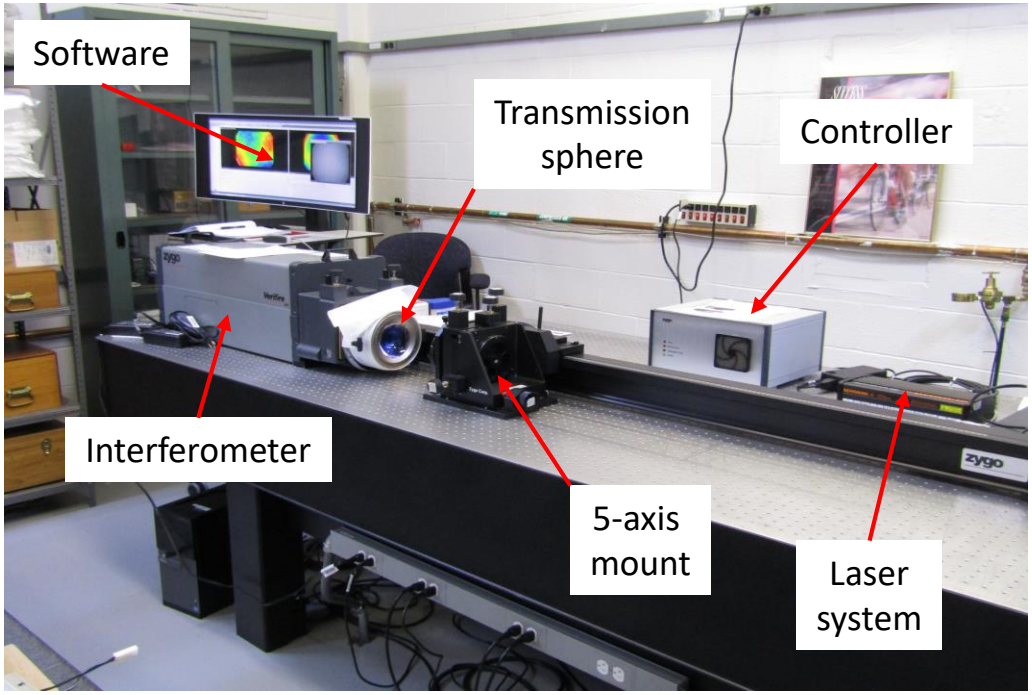
- ROC measurements using laser interferometry is not a new technique and has been around since 1978[1].
  - A fundamental parameter of optical surfaces
- The literature covers areas such as:
  - Refractive index of air corrections due to non-ideal environmental conditions (extrinsic)[2,3]
  - Intrinsic error sources[4,5,6]
  - Error and uncertainty analysis[1,7]
- The literature is sparse relative to applications in calibration laboratories outside of Primary Standards laboratories (e.g., SNL-NM) and National Measurement Institutes (e.g., NIST, NPL, PRB, etc.)



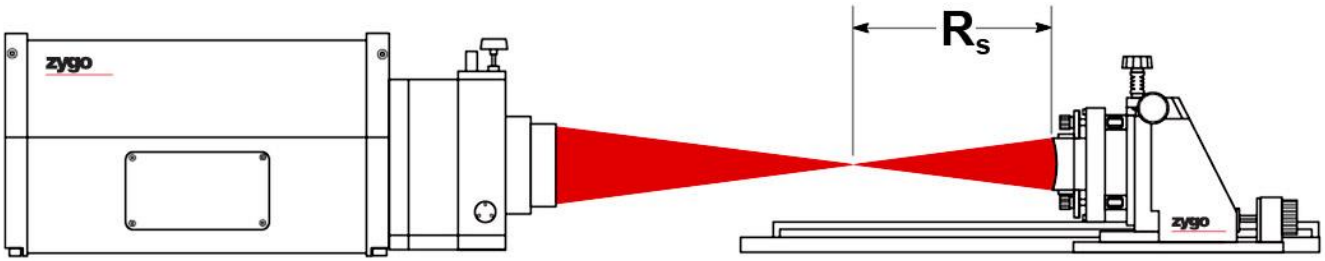
Source: *ZYGO*

Approach: Current Setup at MP&CL

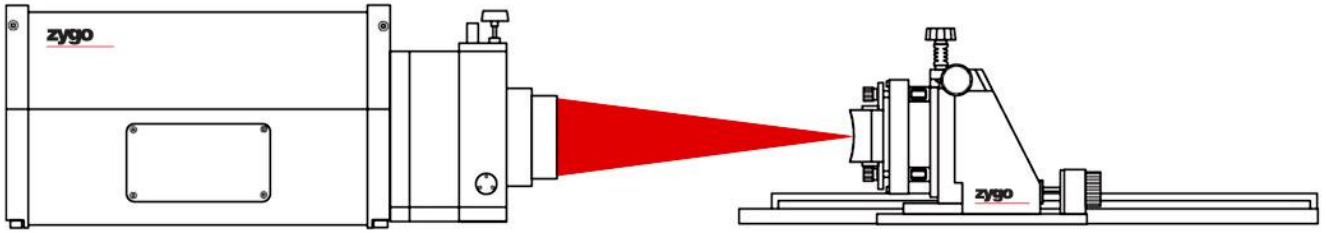
- Measurement system housed in Dimensional Calibration Section
- Measurement Capabilities:
  - Measures surface size and form of reflective materials such as optics, and transmitted wavefront of transparent optics and imaging systems
- Computer Requirements:
  - High-performance Dell PC, Windows 10, 64-bit, Mx™ software
- Mounting Configuration: Horizontal



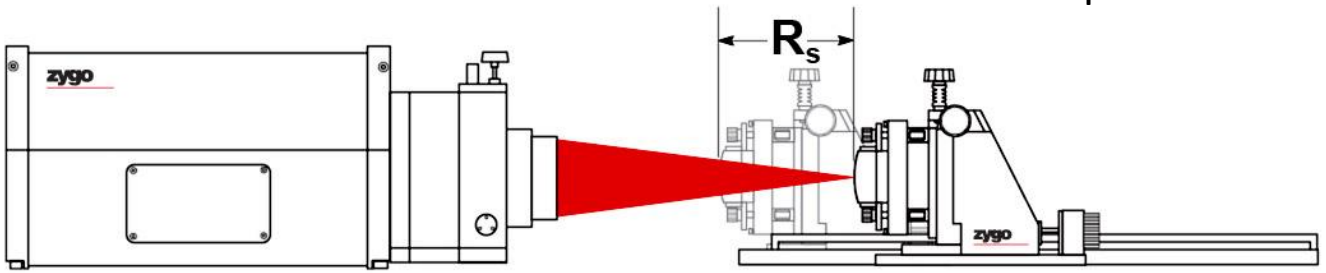
Measurand Definitions



Concave = away from TS/system



Focal point

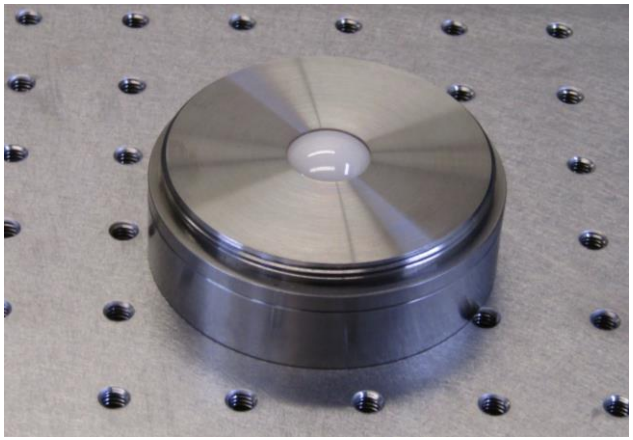


Convex = towards TS/system

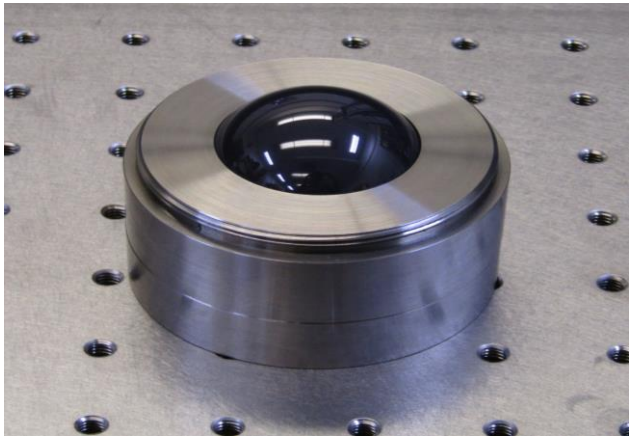
Source: *ZYGO*

Experimental Testing

- Measurands:
  - 12mm ROC, ceramic calibration artifact
  - 24mm ROC, quartz calibration artifact
- Testing setup:
  - 3 appraisers/operators
  - 30 measurements per artifact per operator
    - 90 measurements total for each artifact
- Refractive index of air corrections are applied to the laser measurements to accommodate the non-standard temperatures and relative humidity
- Predictable biases are accounted for and corrections are applied to measurement data
- Results were reported in “Reported Value ± Expanded Uncertainty”



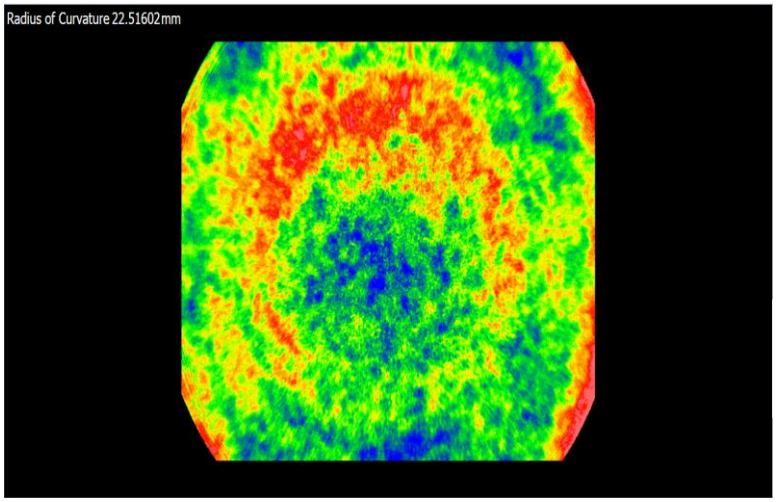
12mm artifact

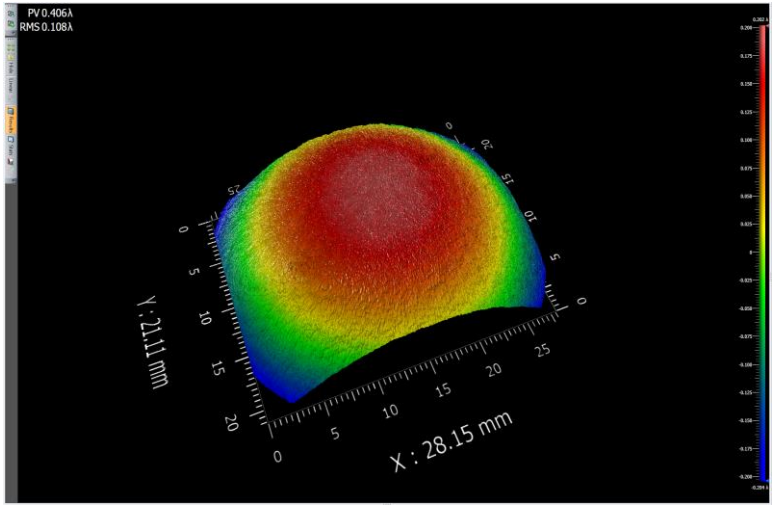


22mm artifact

Residual Map & 3D

- Each measurement results in a map of the residual errors and a ROC value
  - Geometry and tilt is subtracted from measurement data
  - Aids in determining areas that show “irregularities”
- 3D representations show raw data with geometry, tilt and a better look at the “irregularities” such as scratches, dings, dents and manufacturing tool process marks





Measurement Uncertainty

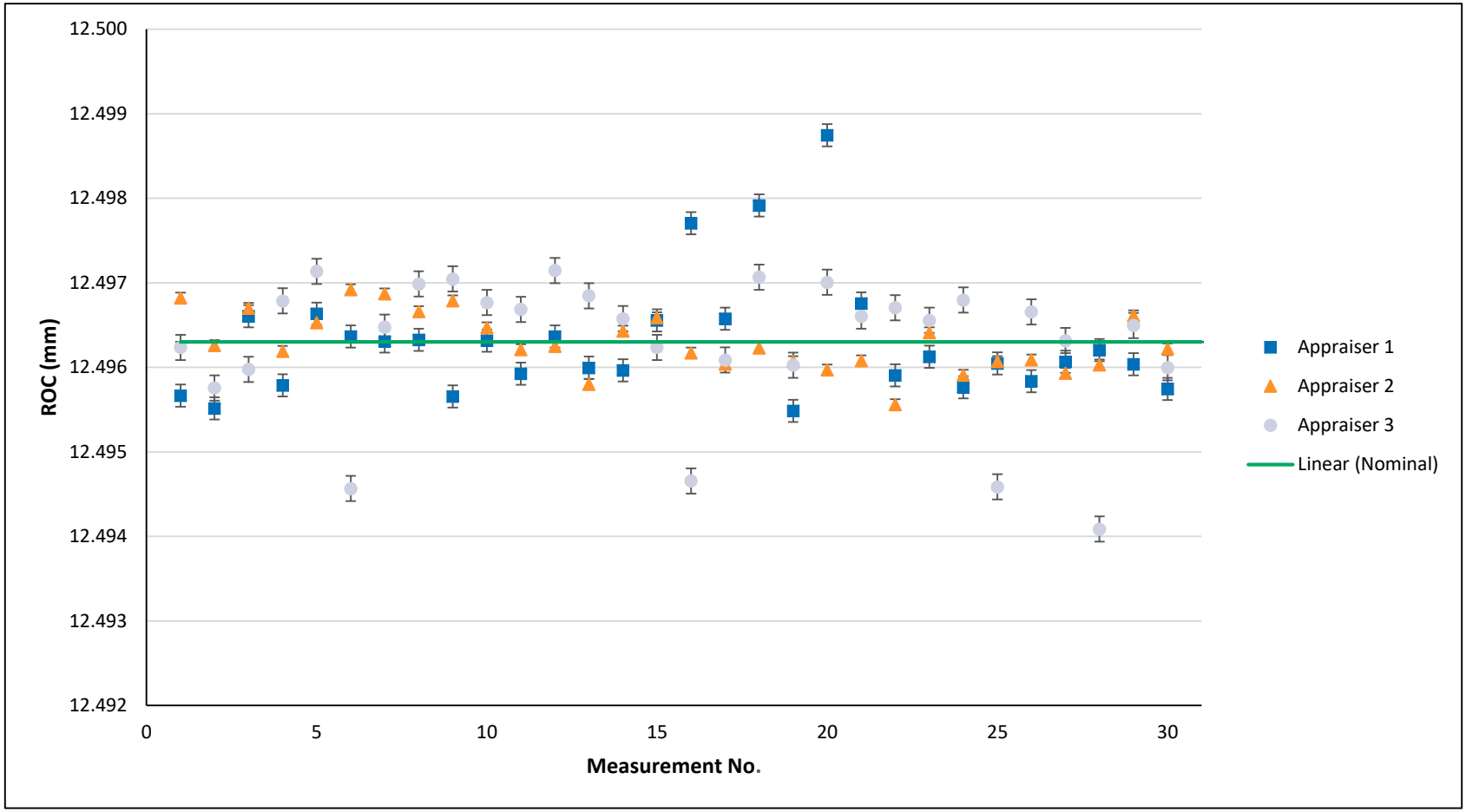
- To validate the measurements, an uncertainty estimation was conducted in the form of a sensitivity analysis as recommended by the GUM[8]
- Statistical variability (Type-A) and known, predictable biases (Type-B) uncertainty sources make up the uncertainty model in the form of a combined standard variance (i.e., uncertainty squared, $u^2(y)$)
- Uncertainty sources are:
  - Measurement Process, s_p
  - Systematic Error, δ
  - Thermal Error, Δr

$$u^2(y) = u^2(s_p) + u^2(\delta) + u^2(\Delta r)$$

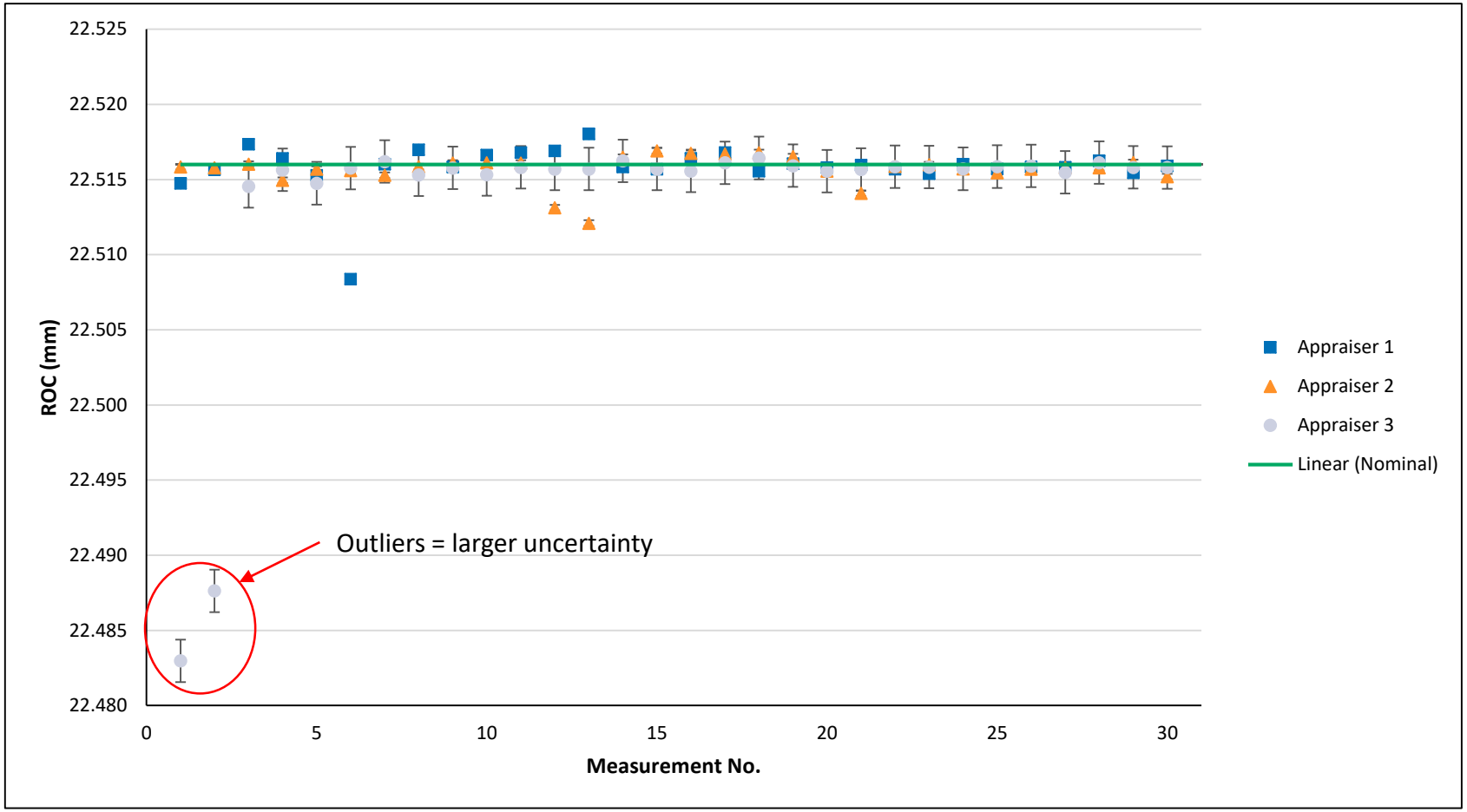
$$u^2(y) = \left(\frac{s_{\bar{r}}}{\sqrt{n}}\right)^2 + \left(\frac{\bar{r} - r_N}{\sqrt{3}}\right)^2 + \left(\frac{\bar{r}}{[1 + \alpha\Delta T]}\sqrt{\Delta T^2 u^2(\alpha) + \alpha^2 u^2(\Delta T)}\right)^2$$

$$u^2(y) = \left(\frac{s_{\bar{r}}}{\sqrt{n}}\right)^2 + \left(\frac{\bar{r} - r_N}{\sqrt{3}}\right)^2 + \left(\bar{r}\sqrt{\Delta T^2\left(\frac{0.1\alpha}{\sqrt{3}}\right)^2 + \alpha^2\left(\frac{\Delta T}{\sqrt{2}}\right)^2}\right)^2, \qquad \alpha\Delta T \ll 1$$

Results: 12mm Artifact



Results: 22mm Artifact



Tabulated Results

Table 1: Reported values and expanded uncertainties of 12mm artifact.

Operator	Reported Value	Expanded Uncertainty (@ k=2)
Appraiser 1	12.49632	0.00026
Appraiser 2	12.49569	0.00077
Appraiser 3	12.49617	0.00020

Table 2: Reported values and expanded uncertainties of 22mm artifact.

Operator	Reported Value	Expanded Uncertainty (@ k=2)
Appraiser 1	22.51584	0.00060
Appraiser 2	22.51362	0.00403
Appraiser 3	22.51567	0.00054

Conclusions

- A calibration process for ROC measurements was presented
  - The measurands under test were a 12mm and 22mm concave ROC artifact which were realized in environmentally-controlled room with a temperature deviation of ±1.0°C
  - Experimental testing was in-line with a repeatability study and predictable biases were accounted and the data was corrected
  - The measurement results were quantified through descriptive statistics and validated via an uncertainty estimation
- Preliminary testing showed that the current calibration process results are nearing the decision rule requirements (need to lower the statistical variations)
- Future work
  - Test the calibration process on known artifacts (e.g., CMM calibration spheres) that have calibration history
  - Develop tooling and calibration process for customer items that are currently calibrated by other means (e.g., 2D measuring machines)

References

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Questions

Thank you!